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STREAMFLOW ANALYSIS AT THE WOOLNER FLATS INDUCED INFILTRATION SITE

TECHNICAL REPORT Nº. 5

GRAND RIVER IMPLEMENTATION COMMITTEE

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GRAND RIVER BASIN WATER MANAGEMENT STUDY

GRAND RIVER STUDY TEAM

TECHNICAL REPORT SERIES

Report #5

STREAMFLOW ANALYSIS AT THE WOOLNER FLATS INDUCED INFILTRATION SITE

PREPARED FOR THE GRAND RIVER IMPLEMENTATION COMMITTEE BY:

Water Modelling Section
Water Resources Branch
Ministry of the Environment
Toronto, Ontario
April 1976

FOREWORD

This report is one of a series of technical documents prepared for the Grand River Basin Water Management Study. The project described herein was undertaken through the Grand River Study Team at the request of the Grand River Implementation Committee.

The material contained in these reports is primarily technical support information and, in itself, does not necessarily constitute policy or management practices. Interpretation and evaluation of the data and findings, in most cases, cannot be based solely on this one report but should be analyzed in light of other reports produced within the comprehensive framework of the overall study. Questions with respect to the contents of this report should be directed to the Co-ordinator of the Grand River Study Team, c/o J. G. Ralston, Water Resources Branch, Ministry of the Environment, 135 St. Clair Avenue West, Toronto.

CREDITS AND ACKNOWLEDGEMENTS

This report was prepared by J.M.H. Coward of the Water Modelling Section, Water Resources Branch, Ministry of the Environment. The author wishes to thank J. D. Pawley of the Regional Municipality of Waterloo and J. Ding and L. Turner of the Ministry of Natural Resources for several useful discussions. The assistance of several staff members of the Water Modelling Section is gratefully acknowledged.

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1. INTRODUCTION

The Regional Municipality of Waterloo has been involved in studies of possible new or additional sources of water supply for the region. One option involves the construction of induced infiltration wells in suitable gravel beds beside the Grand River at Woolner Flats (see Figure 1, Location Map).

In support of this study, the Induced Infiltration Committee of the Regional Municipality of Waterloo requested that the Ministry of the Environment assist in the study by determining the periods of the year when withdrawals from the wells may be limited by degraded downstream quality. In addition, the effects of the existing and proposed dams on the streamflows and on the operation of the induced infiltration wells were to be identified.

The proposed abstraction of river water at the Woolner Flats site is likely to reduce the waste assimilation capacity of the Grand River below this reach. The Kitchener STP is the most significant source of waste loading to be considered below the Woolner Flats site. Flows at this point should be maintained at a level high enough to properly assimilate the waste input and to keep the dissolved oxygen (DO) level in the river within the criteria set by the Ministry of the Environment (1974).*

This study was carried out in three major phases:

1) Determination of the critical streamflow at the Kitchener STP that would maintain the minimum DO in the river above 4, 4.5 and 5 mg/l, for different pollution loads from the Kitchener STP and for zero and full abstraction from the river at the Woolner Flats site.

2) Determination of the probability of occurrence of such critical streamflows.

3) Estimation of effects of dams on the streamflows and on the critical periods.

*Ministry of the Environment (1974). Guidelines and Criteria for Water Quality Management in Ontario.

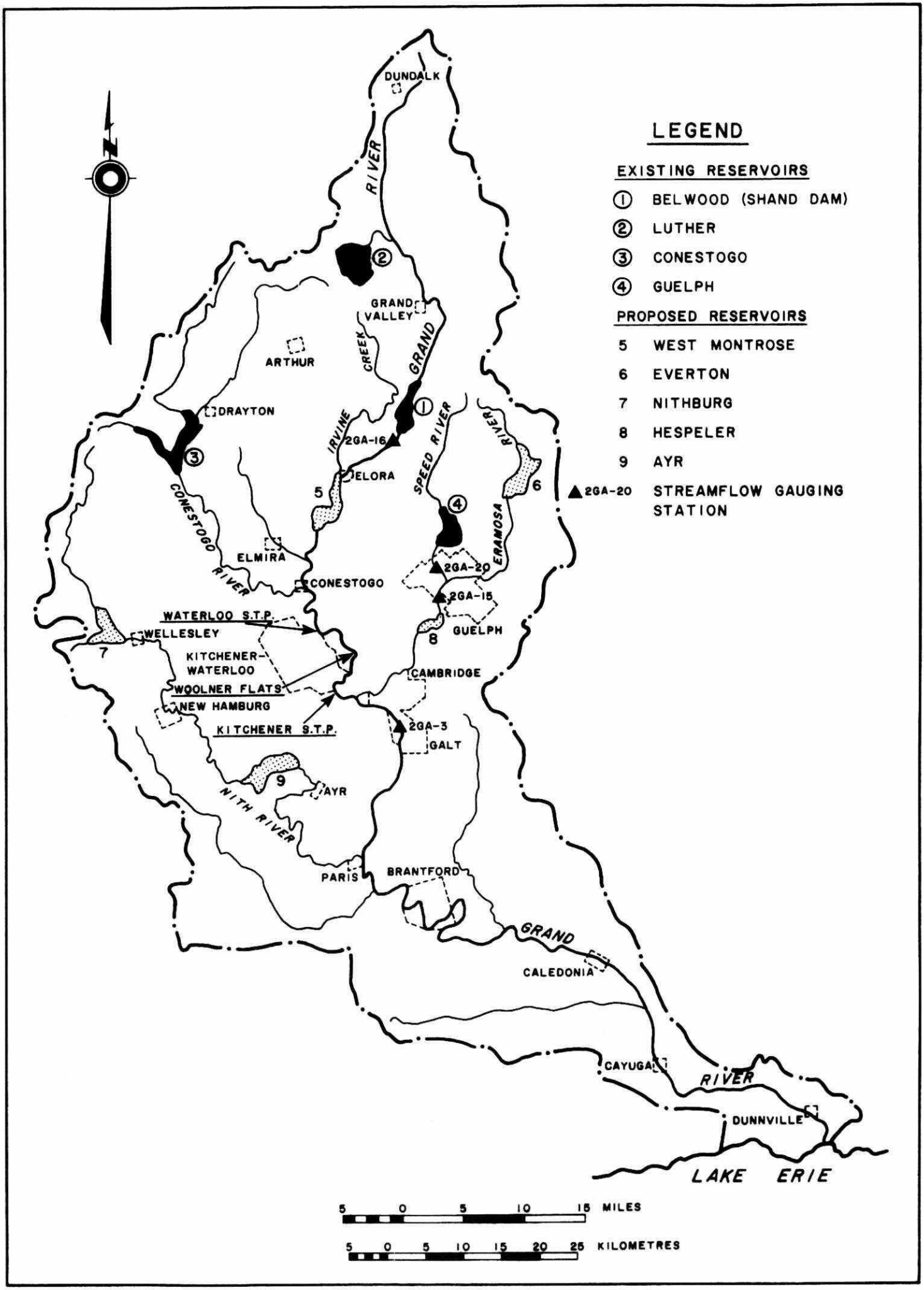

FIGURE 1 - LOCATION MAP

2. FLOW REQUIRED TO MAINTAIN ACCEPTABLE DISSOLVED OXYGEN LEVELS BELOW THE KITCHENER STP

An intensive survey of the river quality below the Kitchener STP was carried out on July 28-30, 1975, and a steady state dissolved oxygen model was developed using these data (see Grand River Technical Report No. 4). It was generally predicted that the minimum DO levels occurred in the reach just upstream of the Galt streamflow gauge and below the Speed River confluence. Figure 2 shows a typical DO plot along the river illustrating that the lowest DO occurs below the Speed River confluence. At higher total oxygen demand (OD) loads from the Kitchener sewage treatment plant (STP), (more than twice survey loads) the minumum DO levels occur further upstream.

The model was run for various flows and STP loadings and from the model results, the relationships between the flows and loadings at a number of DO levels were derived, as shown in Figure 3. The relationships shown in this figure are subject to the limitations of the steady state model, as explained in Section 5 of this report. From Figure 3, the critical flows above the Kitchener STP necessary to maintain the minimum DO levels of 4, 4.5 and 5 mg/l in the river below the plant, were derived and are listed in Table 1. Low quality STP loadings of 0.75, 1.0 and 1.5 times the July 28-30, 1975 survey load of 5,400 kg (12,100 lbs) OD/day and high quality loadings were used. The high quality or nitrified loadings assumed that the total kjeldahl nitrogen in the effluent was reduced to 2 mg/l and the BOD_5 remained at the survey value of 9.6 mg/l (see Table A5, in Grand River Technical Report No. 4). It was predicted from the model that if the STP effluent was nitrified the DO in the river was very insensitive to changes in the STP flow rate from the survey flow (0.67 m^3/s) up to three times survey flow (Figure 3).

The Woolner Flats site is being developed to pump a maximum of 20 MIGPD (1.05 m^3/s) from the induced infiltration wells. Assuming that the major portion of this flow comes directly from the river, the flows necessary to maintain the DO levels at the above STP loadings and with 1 m^3/s of water being abstracted from the river, were calculated and are also listed in Table 1. As the flow gauge near the Kitchener STP has a very short record, and as the minimum DO levels occur near Galt, critical flows were prorated to the Galt gauge. Flow duration curves for natural flows in the Grand and Speed rivers appear characteristically similar; prorating of the critical flows above Kitchener to the Galt gauge (Table 1), downstream of the Speed confluence, on a proportional area basis, was therefore assumed to be correct for the purpose of further statistical flow analysis.

TABLE 1 Critical Flows Required to Maintain DO Levels of 4, 4.5 and 5 mg/l, for four STP Loads and Zero and Full Pumping Rate at Woolner Flats

Minimum DO Level mg/l	Kitchener STP Load, Ratio to July, 1975 Survey Figure[1]	Abstraction from River at Woolner Flats[2] m^3/s	Critical Flow above Kitchener STP m^3/s	(cfs)	Corresponding Critical Flow prorated to Galt m^3/s	(cfs)
4	Nitrified	0	4.8	(169)	6.77	(238)
4	Nitrified	1	5.8	(204)	8.18	(288)
4	0.75	0	6.5	(230)	9.17	(324)
4	0.75	1	7.5	(265)	10.58	(374)
4	1.00	0	7.6	(268)	10.72	(379)
4	1.00	1	8.6	(304)	12.13	(428)
4	1.50	0	10.1	(357)	14.24	(503)
4	1.50	1	11.1	(392)	15.66	(553)
4.5	Nitrified	0	7.7	(272)	10.86	(384)
4.5	Nitrified	1	8.7	(308)	12.27	(433)
4.5	0.75	0	9.9	(350)	13.96	(493)
4.5	0.75	1	10.9	(386)	15.37	(543)
4.5	1.00	0	10.9	(386)	15.37	(543)
4.5	1.00	1	11.9	(420)	16.78	(593)
4.5	1.50	0	13.0	(460)	18.33	(647)
4.5	1.50	1	14.0	(494)	19.74	(697)
5	Nitrified	0	11.5	(406)	16.22	(572)
5	Nitrified	1	12.5	(441)	17.63	(622)
5	0.75	0	13.2	(466)	18.62	(658)
5	0.75	1	14.2	(501)	20.03	(707)
5	1.0	0	14.0	(494)	19.75	(698)
5	1.0	1	15.0	(530)	21.16	(747)
5	1.5	0	16.5	(583)	23.27	(822)
5	1.5	1	17.5	(618)	24.68	(872)

Notes:

1. The nitrified conditions are with the BOD_5 as at survey (9.6 mg/l), the TKN reduced to 2.0 mg/l, and with the STP flow between 1 and 3 times survey flow of 0.67 m^3/s.

2. 1 m^3/s = 35 cfs = 19 MIGPD

From Table 1, the minimum streamflows required for full pumping operations at Woolner Flats can be generally determined. For example, if a minimum DO level of 5 mg/l is to be maintained in the river at the Kitchener STP with present waste loads, then the pumps at Woolner Flats can be placed into partial operation only if the flow above the Kitchener STP is greater than 14.0 m^3/s (i.e., 19.75 m^3/s at the Galt gauge). Full pumping can only occur if the flow without pumping is approximately 21.2 m^3/s, or greater, at the Galt gauge.

3. CRITICAL FLOW PERIODS - PRESENT CONDITIONS

An analysis of the historic streamflow record at the Galt gauge (between 1959-73) was carried out to determine the proportion of each year that the streamflows were below the critical levels listed in Table 1. The analysis was first carried out for flows under the present operating policies of the existing Shand and Conestogo dams.

The streamflow records at Galt were analysed for the annual period of May to October of each year, assuming that low flows in the winter periods do not have as extreme an effect on the quality as low flows during the warmer periods. Figure 4 shows the saturated DO levels in the Grand River, based on water temperature data illustrating that critical DO levels are more likely to occur during the May to October period.

The number of summer days when streamflows were below the stated critical levels was determined for each year for the period 1959-73, for the different STP loads and DO levels. The percentage of the number of critical flow days during a "summer" period of 184 days and the probabilities of occurrence are plotted in Figure 5. From these curves, the number of critical days exceeded at an average return period of 20 years, 5 years, 2 years (median) and 1.2 years (i.e. not exceeded 1 year in 5), and the mean number of days, have been listed in the left portion of Table 2. Based on these results, the relationship between flow above the Kitchener STP and the proportion of critical days is shown in Figure 6 for a number of average return periods.

TABLE 2: Number of Summer Critical Flow Days at Woolner Flats

DO[4]	Load[5]	Pumpage[6]	Number of Summer (May-Oct) Days each Year with Flows Less than Critical[1]									
			Present Reservoir Operation[2]					Improved Reservoir Operation[3]				
			Average Return Period Years				Mean	Average Return Period Years				Mean
			20	5	2	1.2		20	5	2	1.2	
4	Nitrified	0	0	0	0	0	0	0	0	0	0	0
4	Nitrified	1	4	0	0	0	0	3	0	0	0	0
4	0.75	0	20	4	0	0	2	9	2	0	0	1
4	0.75	1	33	13	0	0	6	20	6	0	0	2
4	1.0	0	37	17	0	0	7	24	6	0	0	3
4	1.0	1	59	50	4	0	19	55	15	2	0	7
4	1.5	0	121	103	22	2	46	107	37	6	0	18
4	1.5	1	140	121	59	15	67	134	96	26	4	33
4.5	Nitrified	0	48	18	0	0	8	33	8	0	0	4
4.5	Nitrified	1	81	48	4	1	20	63	18	0	0	8
4.5	0.75	0	116	94	22	1	40	103	44	7	0	22
4.5	0.75	1	136	120	52	9	63	132	74	22	2	39
4.5	1.0	0	136	120	52	9	63	132	74	22	2	39
4.5	1.0	1	151	136	81	28	85	153	103	46	15	57
4.5	1.5	0	162	149	107	48	107	167	129	77	33	77
4.5	1.5	1	169	156	125	66	121	175	145	103	48	99
5	Nitrified	0	145	132	66	18	74	151	96	37	9	52
5	Nitrified	1	156	144	96	39	98	162	121	63	26	70
5	0.75	0	160	154	112	48	111	171	132	77	29	70
5	0.75	1	173	156	127	72	122	177	147	110	55	87
5	1.0	0	162	155	125	57	119	175	140	101	48	83
5	1.0	1	177	160	134	94	130	178	156	131	61	98
5	1.5	0	178	164	149	120	143	180	166	153	70	111
5	1.5	1	182	175	153	127	146	182	169	160	86	117

Notes:

1. Based on the 184-day summer period, in the years 1959-1973.
2. Shand and Conestogo dams, historic operation.
3. Shand, Conestogo and West Montrose dams operating to improve low flows, and the Guelph dam operating with the full reservoir storage used for low flow augmentation.
4. Minimum predicted dissolved oxygen level (mg/l), based on the assumptions of the steady state modelling.
5. Dissolved oxygen load from the Kitchener STP, ratio to July 1975 survey conditions (5400 kg OD/day). The nitrified figures are with the STP flow between 1 and 3 times survey (0.67 m^3/s), TKN reduced to 2 mg/l, and BOD_5 as at survey (9.6 mg/l).
6. Abstraction from the river, m^3/s (1 m^3/s = 35 cfs = 19 MIGPD).

4. EFFECT OF IMPROVED OPERATIONS AND NEW DAMS

Part of the request by the Induced Infiltration Committee was to determine the effects on the Woolner Flats project of new dams and alternative operating policies at the existing dams in the basin. To do this, the yields obtainable from the existing Shand and Conestogo dams were determined under "improved" operating policies designed to increase low flows (Ministry of Natural Resources Technical Report No. 3) and the yields were estimated for the new Guelph dam (built in 1975) and the proposed West Montrose dam. The improved streamflows from the dams were compared to the critical streamflows and the number of critical flow days were determined for these conditions (Table 2).

4.1 Guelph Dam

In order to evaluate the effect of the new Guelph dam, constructed in 1975, on the Speed River, the yield from the dam was estimated by a mass curve analysis, using the eight-year streamflow record at 02GA020 (Speed River above Guelph). The streamflow at the dam site (drainage area 89 sq. miles) was estimated by prorating the gauge streamflow (area 104 sq. miles) by the ratio of the areas. The mass curve for the Guelph dam is shown in Figure 7.

The planned operating policy for the dam is to allow a five foot (1.5 metre) summer drawdown (personal comm., Mr. C. Stephens, Grand River Conservation Authority, 1976), giving flow augmentation storage of 6.1×10^6 m^3 (5,000 acre-ft.). The total reservoir storage is 16.0×10^6 m^3 (13,000 acre-ft.). Based on the average figures at nearby stations, the potential evaporation at the dam was estimated to be 0.5 metres (20 inches) per year, giving a total evaporative loss throughout the summer of about 1.6×10^6 m^3.

Using these two storage figures, minus the evaporative loss, the five smallest yields obtainable are illustrated on Figure 7, and the probable yields at different return periods are shown in Figure 8.

Based on flow analysis of the Shand and Conestogo dams, the seven-day low flows from the Guelph dam were estimated to be approximately 0.75 times the monthly or seasonal low flows. The total augmented flow from the Speed River at the gauge below Guelph (02GA015) was determined by adding the prorated Eramosa flow to the yield from the dam. The calculated flows for a number of average return periods are shown in Table 3, and are compared to the existing flow conditions at the gauge.

TABLE 3: Low Flow Analysis at the Guelph Dam

	Flow in m^3/s (cfs) Average Return Period , in years			
	20	10	5	2
Flow at the Guelph Dam				
Long term yield from dam using full storage	0.97 (34)	1.1 (39)	1.27 (45)	1.56 (55)
7-day yield from dam using full storage	0.73 (26)	0.82 (29)	0.95 (33)	1.17 (41)
Long term yield from dam using 1.5-metre drawdown	0.48 (17)	0.52 (18)	0.58 (20)	0.68 (24)
7-day yield from dam using 1.5-metre drawdown	0.36 (13)	0.39 (14)	0.44 (16)	0.51 (18)
Flow in the Eramosa River				
Prorated 7-day Eramosa River flow	0.25 (9)	0.32 (11)	0.43 (15)	0.66 (23)
Flow below Guelph at 02GA015				
Natural 7-day low flow at 02GA015 during 1953-1973	0.51 (18)	0.62 (22)	0.76 (27)	0.99 (35)
Calculated 7-day low flow at 02GA015 using 1.5-metre drawdown from the reservoir	0.61 (22)	0.71 (25)	0.86 (30)	1.17 (41)
Calculated 7-day low flow at 02GA015 using full storage from the reservoir	0.98 (35)	1.14 (40)	1.38 (49)	1.83 (65)

It can be seen from Table 3 that the low flows would be approximately 0.1 m^3/s larger than the natural flows, if the dam is operated under the proposed 1.5-metre summer drawdown. If the full reservoir storage is used, the increase in low flows varies from 0.47 to 0.84 m^3/s.

4.2 SHAND, CONESTOGO AND WEST MONTROSE DAMS

A study was carried out by the Conservation Authorities Branch of the Ministry of Natural Resources to determine the optimum reservoir yields from the Shand, Conestogo and the proposed West Montrose dams (see Grand River Technical Report No. 3). That reservoir yield study gave the monthly discharges that could be maintained by the dams under an operating policy designed to increase the low flows. The monthly discharges were compared to the historic records and the differences in flow for each summer month from 1959 to 1973 were calculated. The increase in flow due to the West Montrose dam was calculated based on the streamflow record at Belwood (02GA016), prorated for the drainage area of the dam.

The daily streamflow record at Galt for each summer month was adjusted by the increased monthly streamflow due to improved low flow policies for the Shand, Conestogo and West Montrose dams. The Guelph dam was assumed to supply an additional 0.1 m^3/s if the summer drawdown was 1.5 metres, and 0.6 m^3/s if the full reservoir storage was used for low flow augmentation. The modified streamflows at Galt were then compared to the critical streamflows and the probability of exceedance was calculated as for the existing flows.

The above analysis was carried out for the improved operation of the Shand and Conestogo dams, and the proposed operation of the Guelph dam, omitting the West Montrose dam. It was found that the number of critical flow days was very similar to the values obtained from the historic streamflows; operation of the dams in this fashion had no significant effect on the number of critical flow days.

The analysis was then carried out for the Shand, Conestogo and West Montrose dams operated for improved low flows, and the Guelph dam for full low flow augmentation. This modification did change the number of critical days; the results of this analysis are shown in figures 9 and 10, and are listed in the right hand portion of Table 2.

The operation of the proposed and existing dams to improve the low flow values had the effect of making the streamflows less variable than the historic record, by increasing the low flows and reducing some of the high flows during the summer. For the conditions which gave a relatively low critical flow (generally with the DO criteria of 4 mg/l) the improved dam operation gave a decrease in the number of critical flow days over these obtained with the historic flow record. However, at higher critical flows (generally with the DO criteria of 5 mg/l, when the critical flow was often higher than the mean summer flow), the improved dam operation had the effect of decreasing some of the higher summer streamflows below the critical level during dry years, and thus increasing the number of critical flow days at long return periods compared to those obtained with the historic record (Table 2).

5. DISCUSSION

The results of the analyses show the number of days in a 184-day summer period when pumpage from the Woolner Flats wells is likely to significantly degrade the downstream quality in the Grand River. The analysis was carried out both for the present flow conditions and for the present and the proposed dams operated to improve the low flows in the river.

The results of this study are dependant on the assumptions and limitations of the steady state DO model, which are described in the Grand River Technical Report No. 4. The basic assumption is that most of the conditions in the river during summer months are similar to those that occurred during the July 1975 survey. In particular, the following conditions should be substantially similar to those at the survey:

a) upstream quality
b) temperature of the water (24^{o}C at survey)
c) sunlight, biomass and physical characteristics of the river,
d) STP load proportion of carbonaceous oxygen demand to nitrogenous oxygen demand.

Because of these restrictions, the critical flow figures (in Table 1) should not be construed as the exact values applicable throughout each summer. The critical flow values at any time would have to be found by consideration of the river conditions at that time. As the survey represented approximately the 'typical' summer conditions, the critical flow days listed in Table 2 are subject to less errors than the critical flow values in Table 1.

The figures in Table 2 represent the number of critical flow days in the summer period. If the load and quality criteria are such that the number of critical flow days are small (less than, say, 50 days a summer) there would probably be very few winter days when critical conditions occurred. In these cases the number of critical flow days in the summer would be similar to the total number throughout the whole year. However, in more stringent conditions, when the number of summer critical flow days is high (over 150 days a summer), then many winter days as well may experience critical conditions. In these cases, the number of critical flow days in a year would be higher than the number in the summer as listed in Table 2. To better determine the total number of critical flow days throughout the year would require further analysis, which would include dynamic quality modelling; this was beyond the scope of the present study.

The STP load during the July 1975 survey was 5400 kg/day. The mean load during 1974 and 1975 were 6200 and 6500 kg/day, respectively, which are approximately 15 and 20 per cent higher than the survey loads. The projected or actual STP loads should be used for predicting the number of critical flow days under specified conditions.

In making use of the results of this report, the number of critical flow days can be found under specified conditions by referring to Table 2. Under different or intermediate conditions, the number of critical flow days can be found by using Figure 3 and either Figure 6 or Figure 10. The critical flow above the Kitchener STP can be estimated at any STP load and at a number of specified minimum DO levels in the river from Figure 3. Any proposed pumpage from the Woolner Flats wells should be added onto this critical flow. The percentage of summer critical flow days can then be found at specified average return periods by using Figure 6 (with the present reservoirs operating under the present conditions) or Figure 10 (with the present and proposed reservoirs operating under improved low flow conditions).

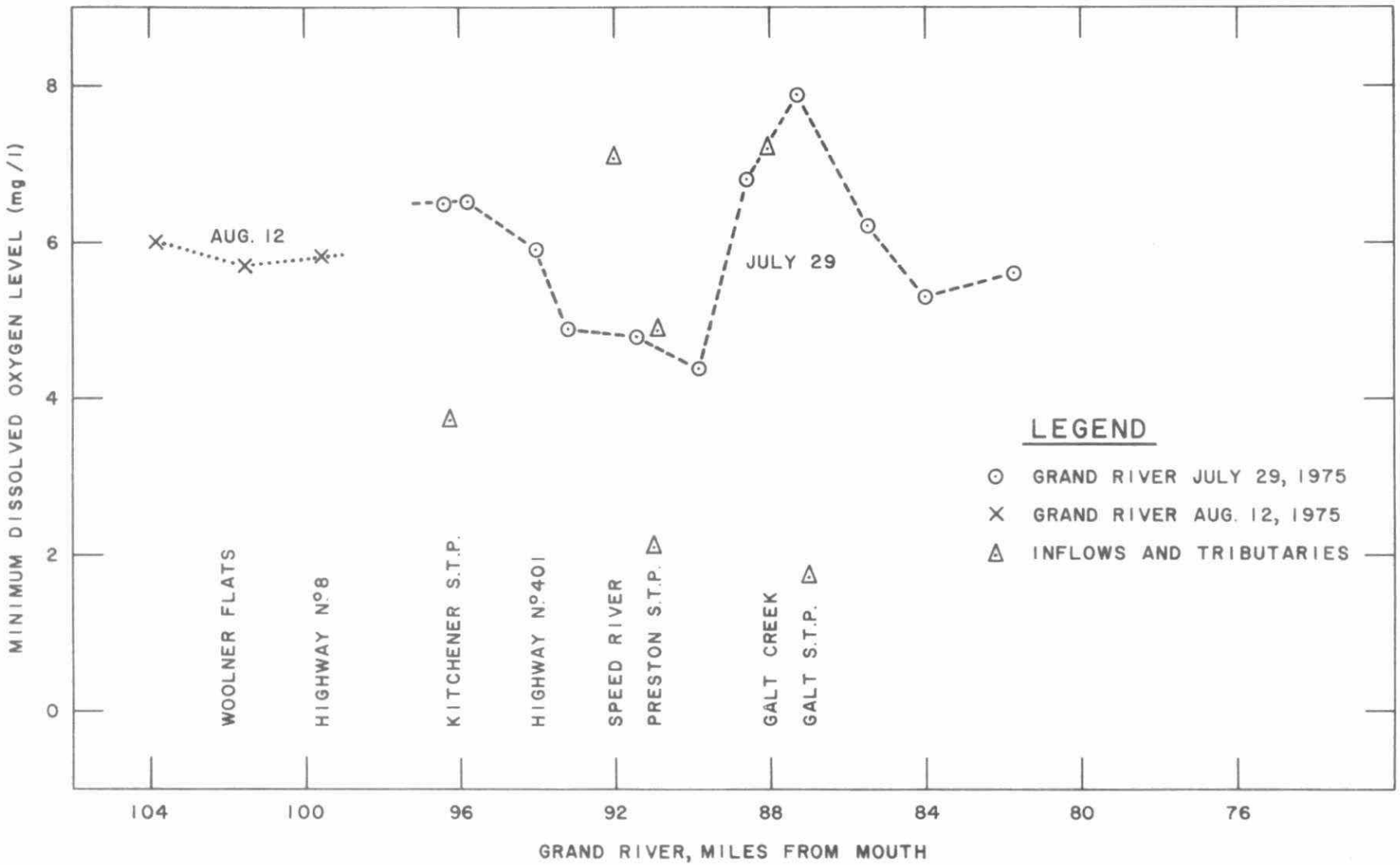

FIGURE 2 - MINIMUM D.O. LEVELS ALONG THE GRAND RIVER

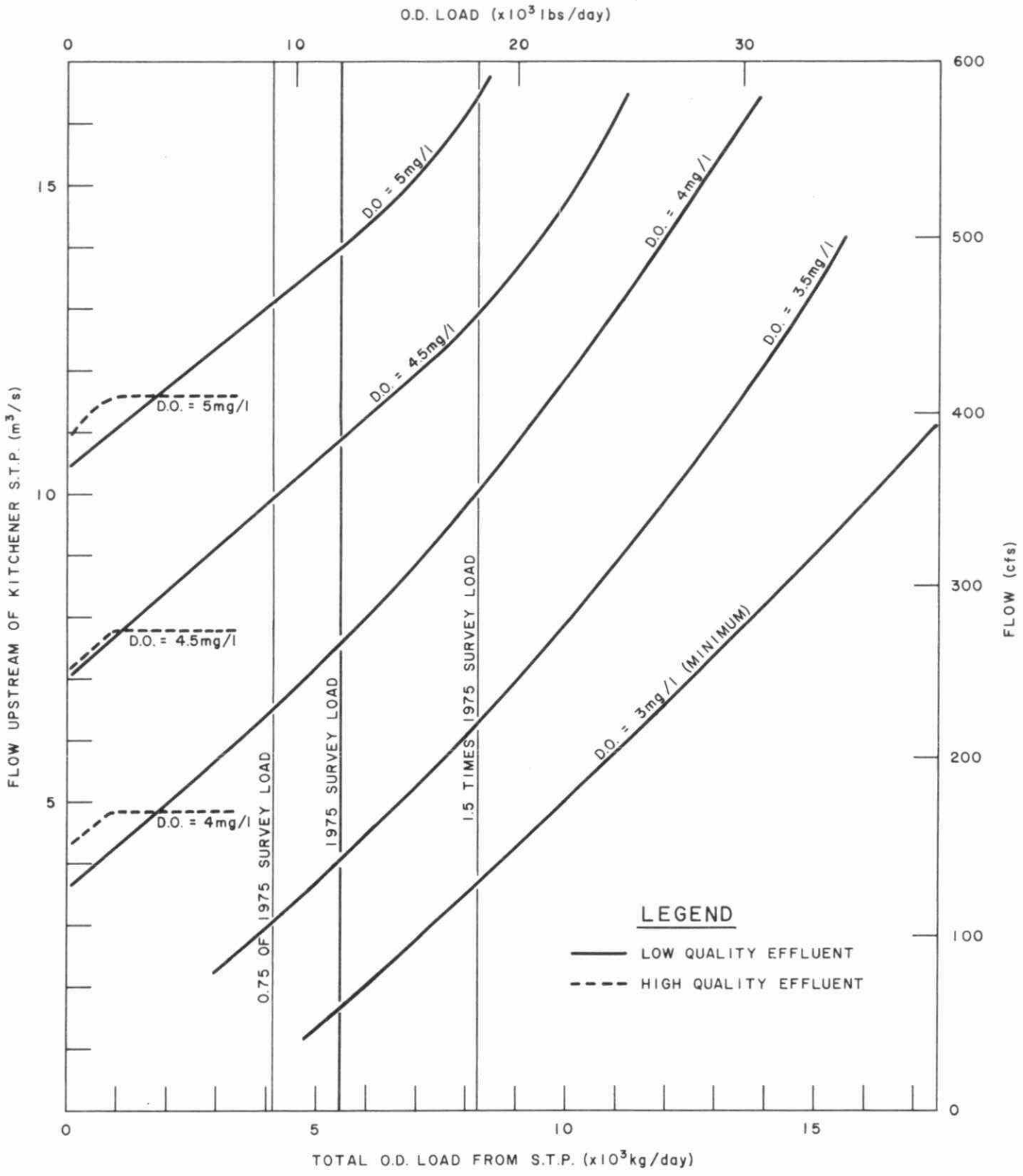

FIGURE 3 – RELATIONSHIP BETWEEN FLOW AND LOADING AT THE KITCHENER S.T.P. FOR A NUMBER OF MINIMUM D.O. LEVELS, PREDICTED FROM STEADY STATE MODELLING

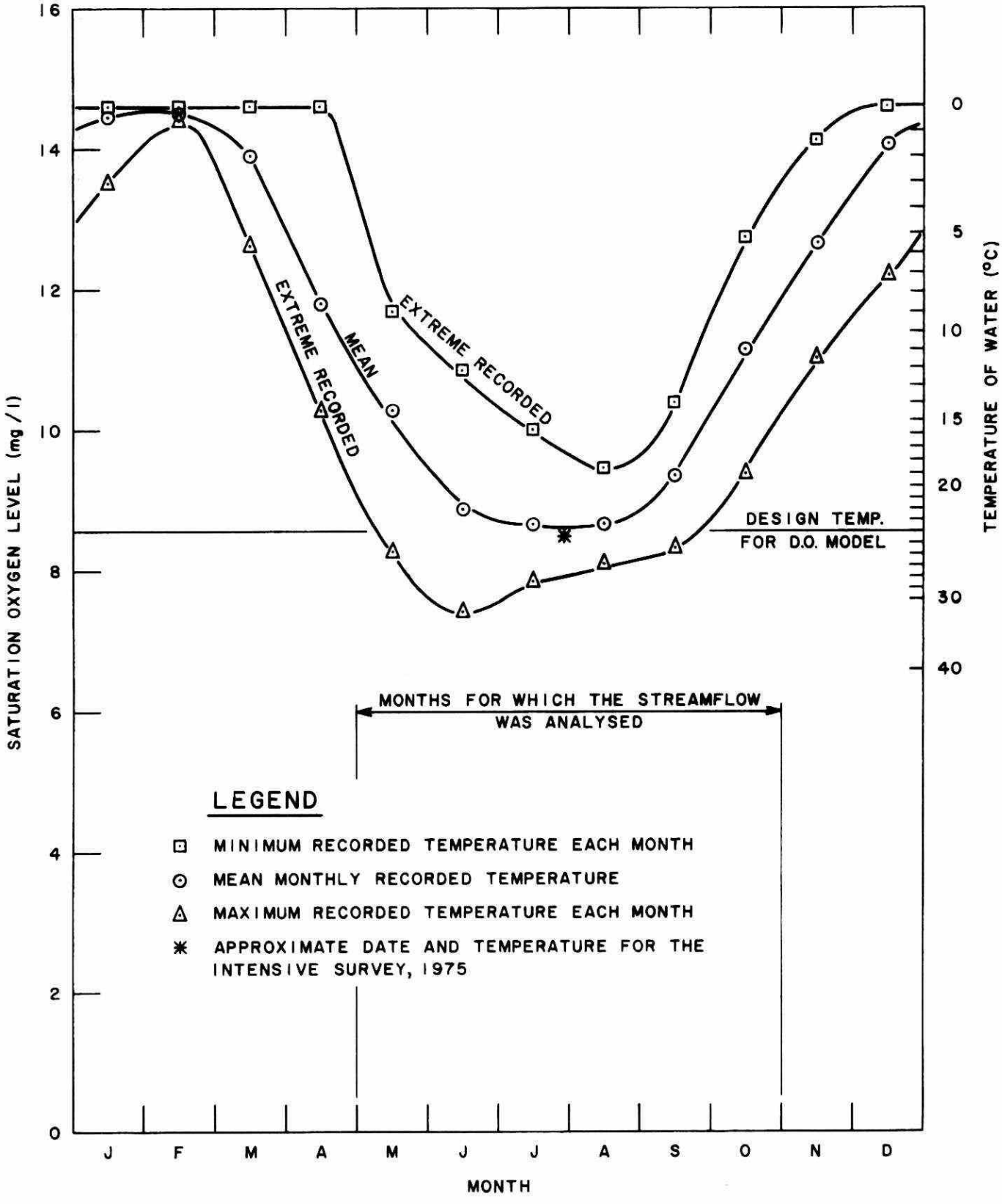
SATURATION OXYGEN LEVEL (mg/l)
TEMPERATURE OF WATER (°C)
MONTH
J F M A M J J A S O N D
0 2 4 6 8 10 12 14 16
0 5 10 15 20 30 40
EXTREME RECORDED
MEAN
EXTREME RECORDED
DESIGN TEMP. FOR D.O. MODEL
MONTHS FOR WHICH THE STREAMFLOW WAS ANALYSED
LEGEND
MINIMUM RECORDED TEMPERATURE EACH MONTH
MEAN MONTHLY RECORDED TEMPERATURE
MAXIMUM RECORDED TEMPERATURE EACH MONTH
APPROXIMATE DATE AND TEMPERATURE FOR THE INTENSIVE SURVEY, 1975

FIGURE 4 - SATURATED MONTHLY D.O. LEVELS IN THE GRAND RIVER, BASED ON TEMPERATURE DATA AT 10 SITES FOR THE PERIOD 1964-1974

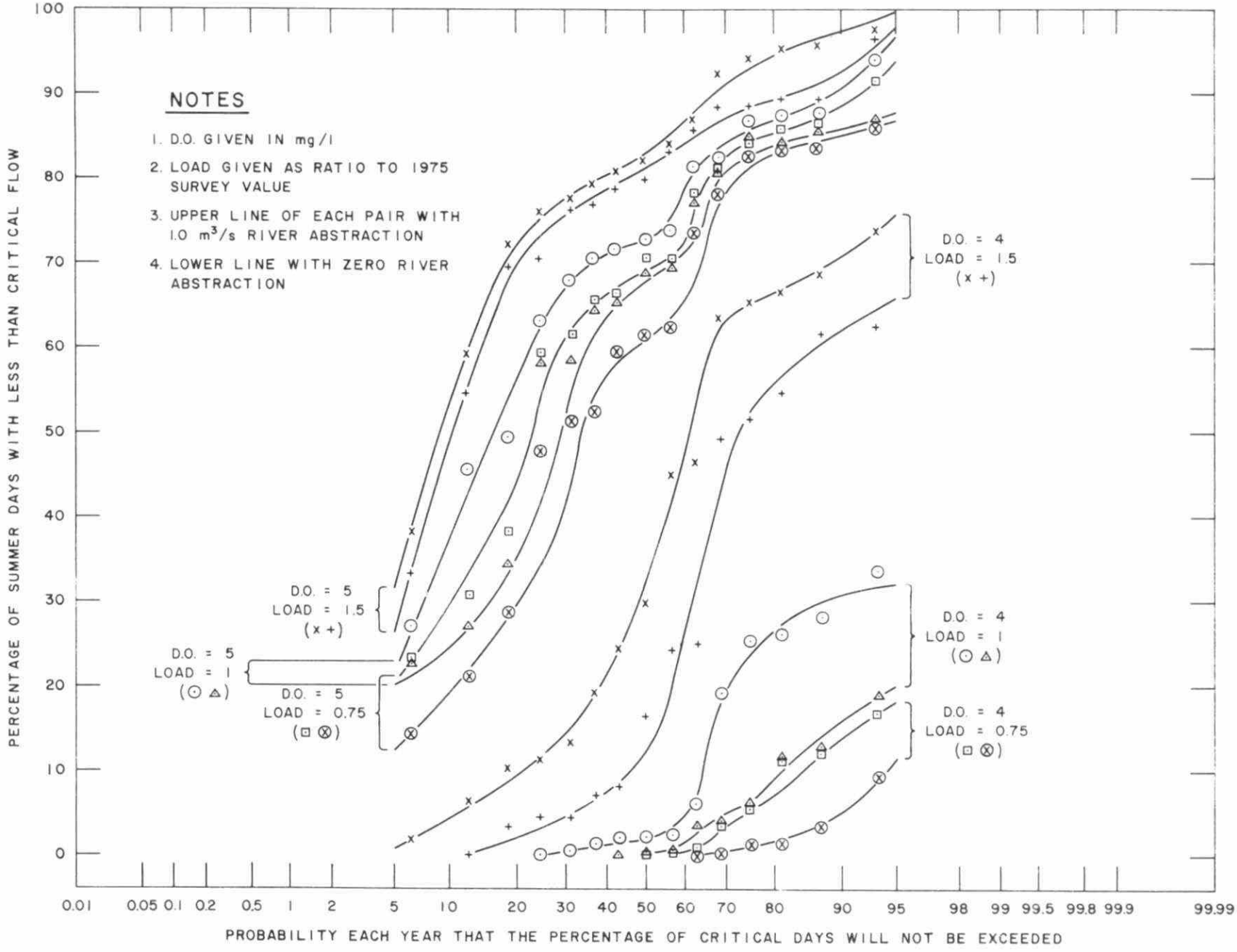
NOTES
1. D.O. GIVEN IN mg/l
2. LOAD GIVEN AS RATIO TO 1975 SURVEY VALUE
3. UPPER LINE OF EACH PAIR WITH 1.0 m³/s RIVER ABSTRACTION
4. LOWER LINE WITH ZERO RIVER ABSTRACTION
D.O. = 4 LOAD = 1.5 (x +)
D.O. = 5 LOAD = 1.5 (x +)
D.O. = 5 LOAD = 1 (⊙ △)
D.O. = 5 LOAD = 0.75 (⊡ ⊗)
D.O. = 4 LOAD = 1 (⊙ △)
D.O. = 4 LOAD = 0.75 (⊡ ⊗)
PERCENTAGE OF SUMMER DAYS WITH LESS THAN CRITICAL FLOW
PROBABILITY EACH YEAR THAT THE PERCENTAGE OF CRITICAL DAYS WILL NOT BE EXCEEDED
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.5 99.8 99.9 99.99
0 10 20 30 40 50 60 70 80 90 100

FIGURE 5 – PERCENTAGE OF CRITICAL FLOW DAYS TO THE PROBABILITY OF OCCURRENCE FOR PRESENT CONDITIONS OF DAM OPERATION (SHAND AND CONESTOGO, 1975)

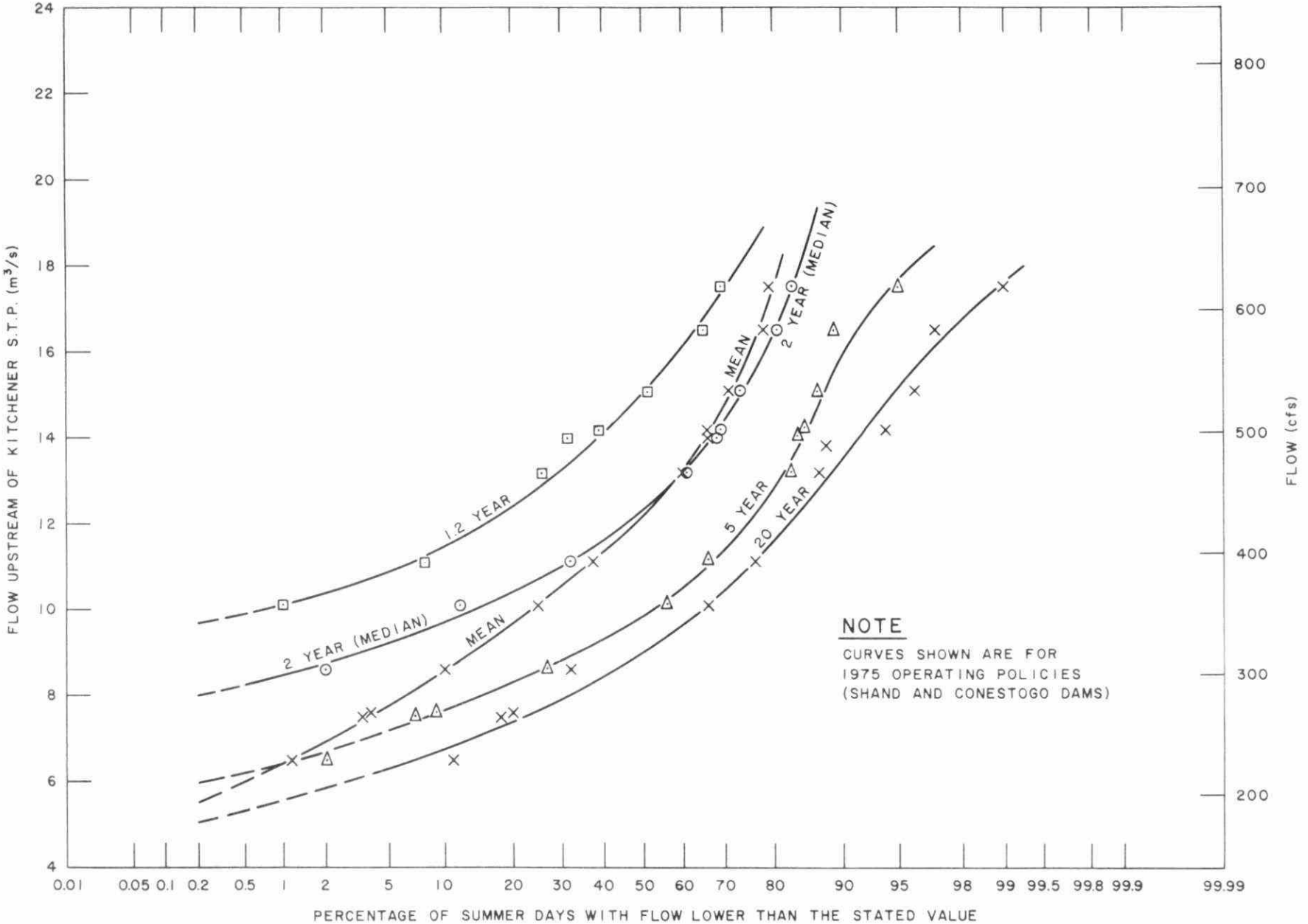

FIGURE 6 - RELATIONSHIP BETWEEN FLOW UPSTREAM OF KITCHENER S.T.P. AND THE PROPORTION OF CRITICAL FLOW DAYS FOR SELECTED AVERAGE RETURN PERIODS, FOR THE 1975 DAM OPERATING POLICIES

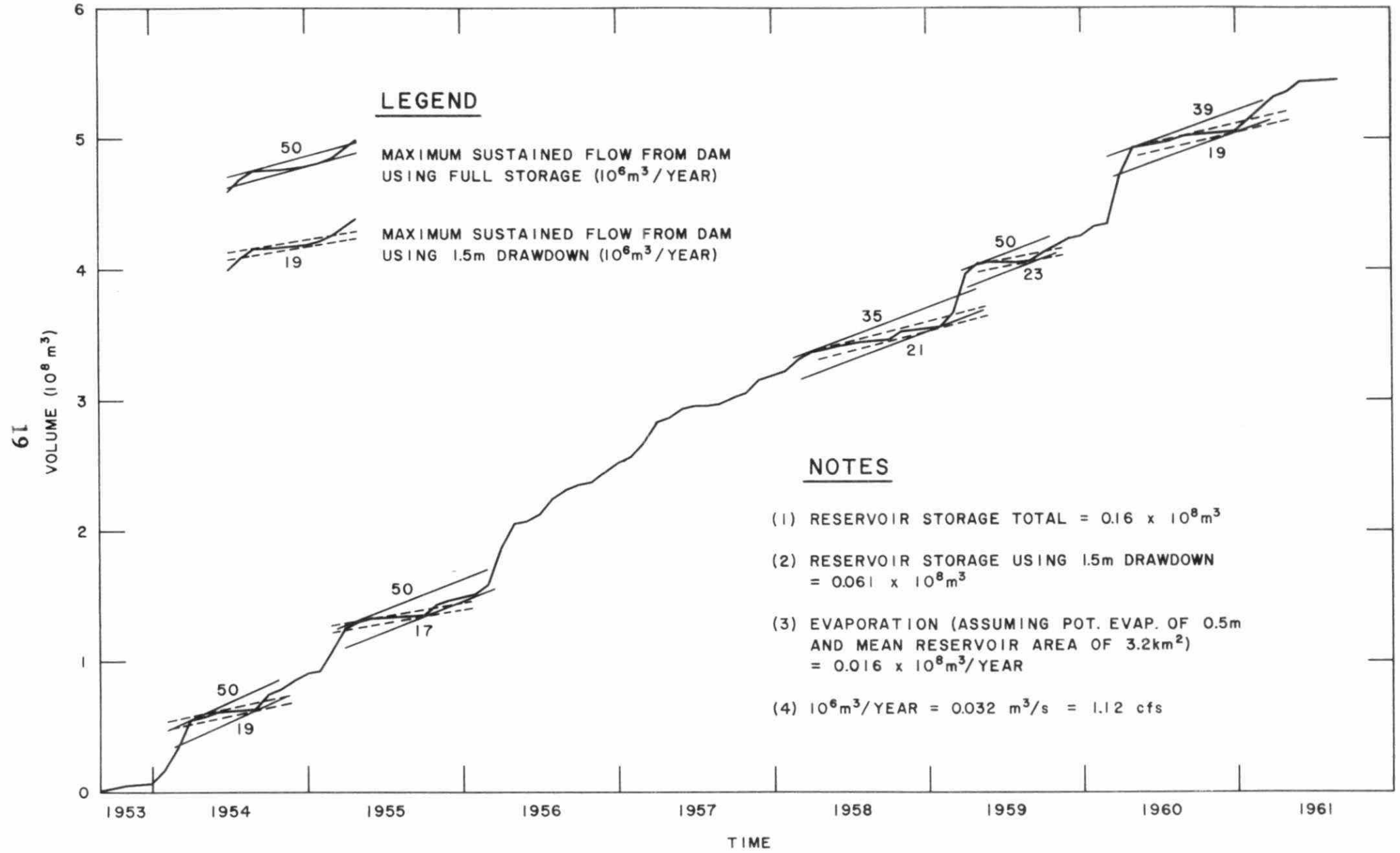

FIGURE 7 – MASS CURVE FOR THE GUELPH DAM

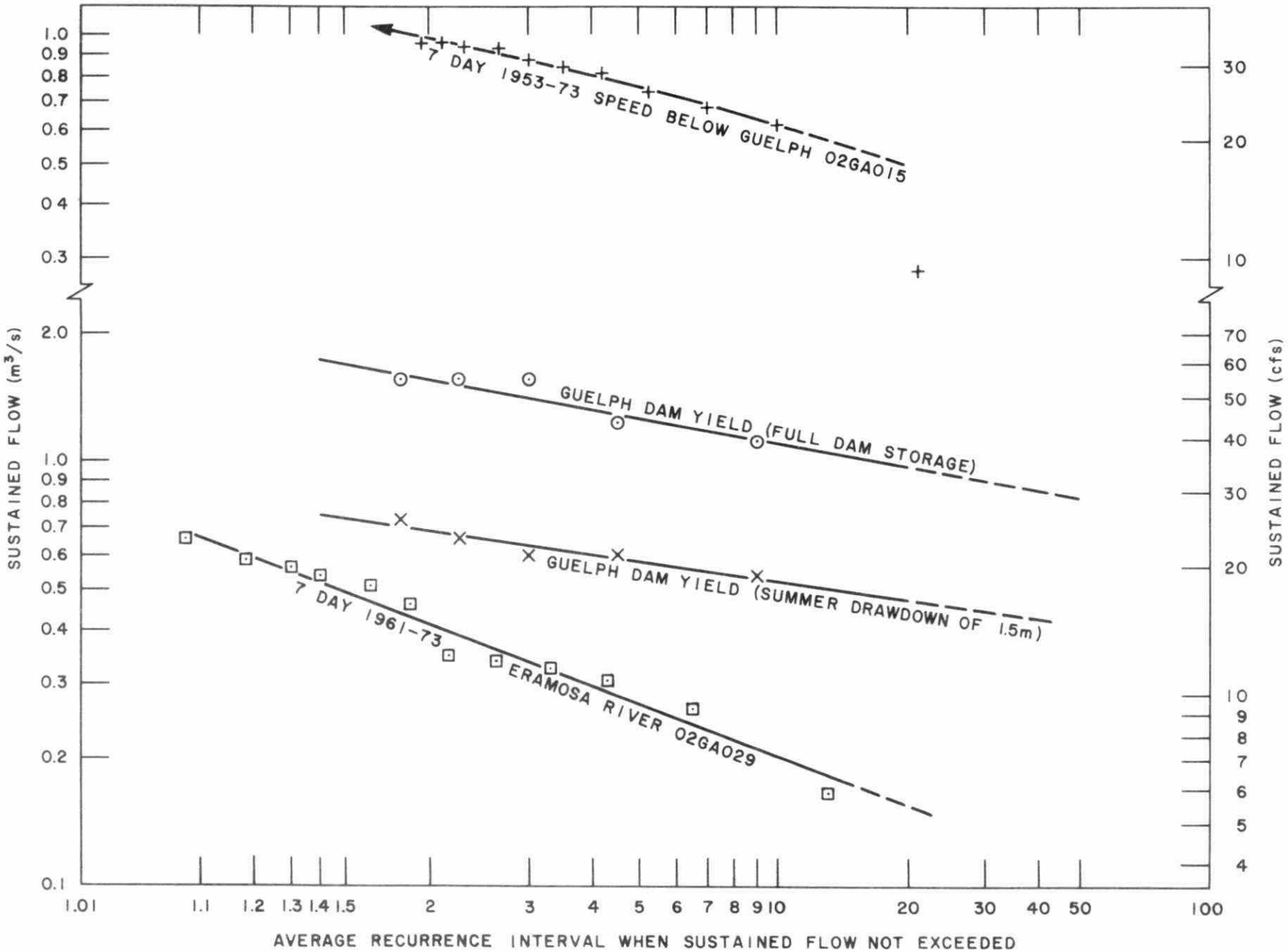

FIGURE 8 – LOW FLOW ANALYSIS FOR THE GUELPH DAM

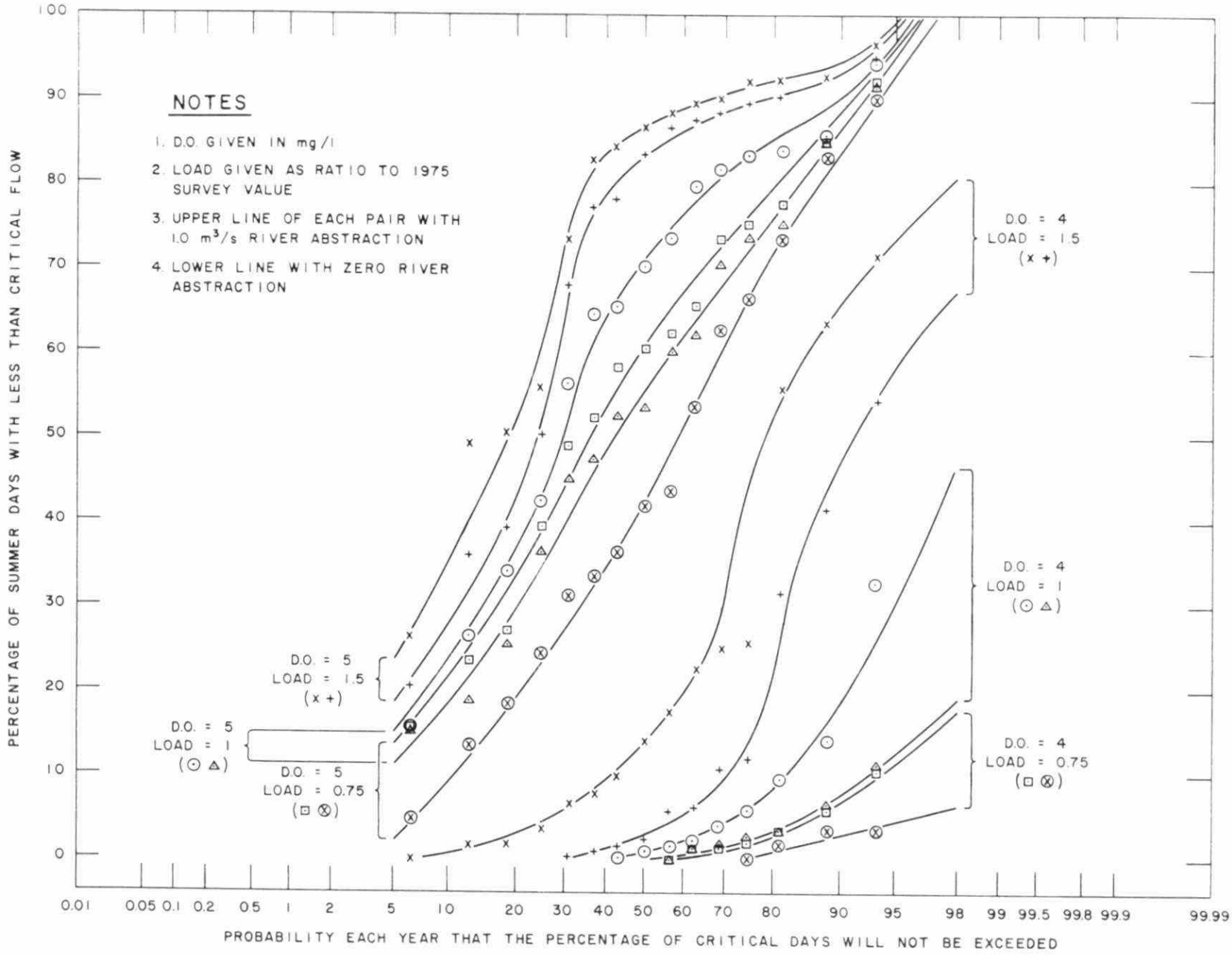
NOTES
1. D.O. GIVEN IN mg/l
2. LOAD GIVEN AS RATIO TO 1975 SURVEY VALUE
3. UPPER LINE OF EACH PAIR WITH 1.0 m³/s RIVER ABSTRACTION
4. LOWER LINE WITH ZERO RIVER ABSTRACTION
D.O. = 4 LOAD = 1.5 (x +)
D.O. = 4 LOAD = 1 (⊙ △)
D.O. = 4 LOAD = 0.75 (□ ⊗)
D.O. = 5 LOAD = 1.5 (x +)
D.O. = 5 LOAD = 1 (⊙ △)
D.O. = 5 LOAD = 0.75 (□ ⊗)
PERCENTAGE OF SUMMER DAYS WITH LESS THAN CRITICAL FLOW
0 10 20 30 40 50 60 70 80 90 100
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.5 99.8 99.9 99.99
PROBABILITY EACH YEAR THAT THE PERCENTAGE OF CRITICAL DAYS WILL NOT BE EXCEEDED

FIGURE 9 – PERCENTAGE OF CRITICAL FLOW DAYS TO THE PROBABILITY OF OCCURRENCE FOR IMPROVED DAM OPERATION (SHAND, CONESTOGO, WEST MONTROSE AND GUELPH DAMS)

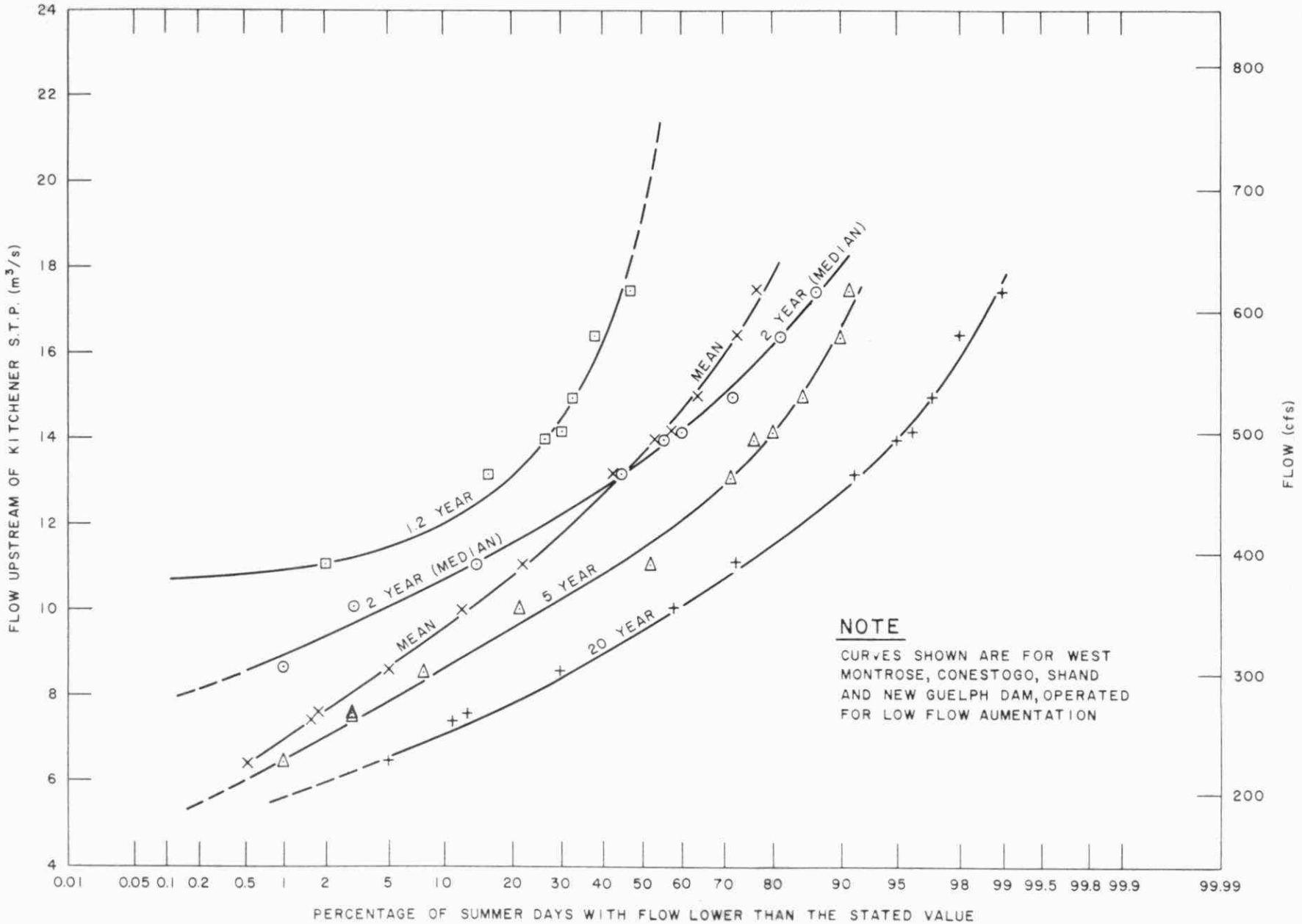
FLOW UPSTREAM OF KITCHENER S.T.P. (m^3/s)
FLOW (cfs)
PERCENTAGE OF SUMMER DAYS WITH FLOW LOWER THAN THE STATED VALUE
1.2 YEAR
2 YEAR (MEDIAN)
MEAN
5 YEAR
20 YEAR
NOTE
CURVES SHOWN ARE FOR WEST MONTROSE, CONESTOGO, SHAND AND NEW GUELPH DAM, OPERATED FOR LOW FLOW AUMENTATION

FIGURE 10 – RELATIONSHIP BETWEEN FLOW UPSTREAM OF KITCHENER S.T.P. AND THE PROPORTION OF CRITICAL FLOW DAYS FOR SELECTED AVERAGE RETURN PERIODS, FOR IMPROVED DAM OPERATING POLICIES

TC
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1976

Streamflow analysis at the Woolmer flats induced infiltration site /

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